Performance Enhancement of Large Area Solar cells by incorporating Nanophosphors:

A ZnOS Demonstrator Solar Cell and its Efficiency

High quality ternary $ZnO_{1-x}S_x$ ($0\leq x\leq 1.0$) nanocrystals in the whole composition range were synthesized for the first time by chemical method. The composition dependence ($0\leq x\leq 1.0$) of band gap, multi-phonon resonant Raman scattering and photoluminescence studies were carried out in detail. The energy band gaps of these ternary $ZnO_{1-x}S_x$($0\leq x\leq 1.0$) nanocrystals show strong bandgap bowing of 3.7 eV. The photoluminescence efficiency of the ternary nanocrystals is demonstrated in its use for enhancement of photovoltaic cell efficiency. Preliminary results demonstrates the 3% enhancement in the efficiency of ZnOS Demonstrator SolarCell with the below visible radiation.

At present, Si-solar cells dominate the market of photovoltaic devices. Single crystalline semiconductor Si has energy band gap 1.1 eV. This suggests that Si absorbs all the radiation above Eg=1.1 eV (corresponds to a wavelength 1200 nm). Most of the Si-based photovoltaic devices take advantage of the fact that they can be made in large area and absorb most of the visible light of the solar spectrum which can further be enhanced by coating nanocrystals for good absorbance, as they have large surface to volume ratio. The electromagnetic spectrum that Ultraviolet (UV) light covers, can be subdivided in three segments; UVA 320nm to 400 nm, UVB 280nm -320 nm and UVC below 280 nm. The Sun emits ultraviolet radiation in the UVA, UVB, and UVC bands, but because of absorption in the atmosphere's ozone layer, 99% of the ultraviolet radiation that reaches the Earth's surface is UVA. Figure 1a shows solar spectrum already being utilized by the solar cells.

The peak wavelength of the conversion efficiency for single crystalline solar cell is about 550 nm and then begins to drop rapidly as wavelength moves toward UV. If there is a way to convert all the UV radiation between 350 nm to 450 nm as well as deep blue between 450 nm to 500 nm to photons emitting in the range of 550 nm that matches well with the peak-response of the Si-solar cell, energy conversion efficiency will increase. Simple estimate using the area under the curve at peak response at 550 nm, efficiency of Si solar cells can be enhanced by 12%. (For this estimate it was assumed that all UV/Blue photons from sunlight are down converted to about 550 nm, where Si-solar cell peak-efficiency occurs. A down-conversion efficiency of 80% was used for the calculation. For example a 15% efficiency solar cell when modified with nanocrystals, efficiency of solar cell is 16.8%. Experimentally we have demonstrated this by

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Rameshwar Nath Bhargava

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14. ABSTRACT
High quality ternary ZnO1-xSx (0≤x≤1.0) nanocrystals in the whole composition range were synthesized for the first time by chemical method. The composition dependence (0≤x≤1.0) of band gap, multi-phonon resonant Raman scattering and photoluminescence studies were carried out in detail. The energy band gaps of these ternary ZnO1-xSx(0≤x≤1.0) nanocrystals show strong bandgap bowing of 3.7 eV. The photoluminescence efficiency of the ternary nanocrystals is demonstrated in its use for enhancement of photovoltaic cell efficiency. Preliminary results demonstrate a 3% enhancement in the efficiency of ZnOS Demonstrator Solar Cell. To enhance the efficiency further, it is recommended 1) to improve the x values of down-conversion of the ZnO1-xSx (0≤x≤1.0) layers and luminescence activator center and 2) to improve the interface between nanophosphors of Si solar cells, as well as optimizing the thickness (in mm) to absorb and down conversion efficiently.

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recording absorbance at fixed wavelength of 350nm, 400nm and 450nm. We got maximum absorbance at 400 nm for $ZnO_{0.7}S_{0.3}$ composition and is consisted with our results for highest bandgap bowing and PLE results.

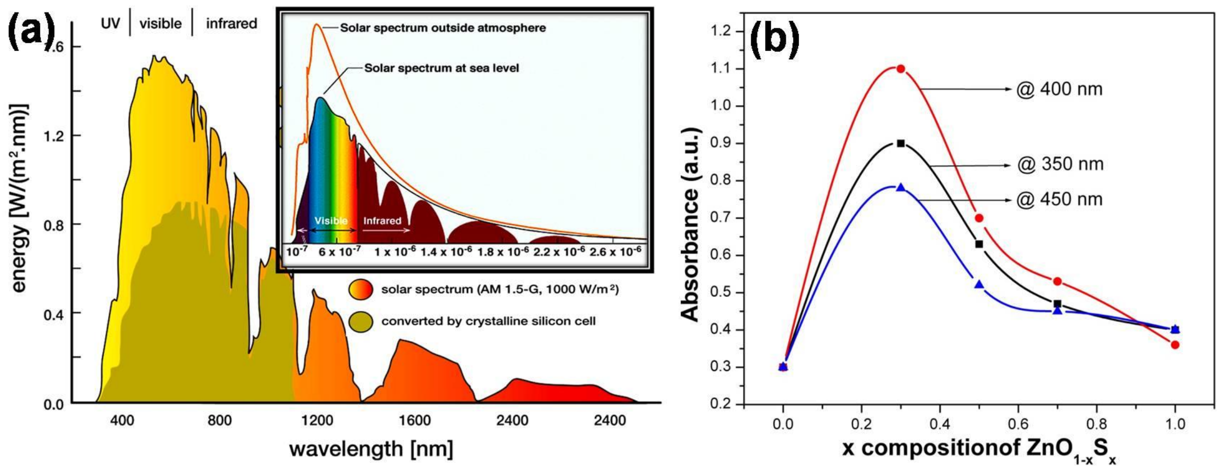

Figure1: Solar Spectrum already being utilized by the solar cells. The area shaded in green represents the achievable energy conversion efficiency in crystalline Si solar panel as a function of the wavelength.

The operating regime of the solar cell is the region in which cell delivers power, i.e. from 0 to V_{oc}. The cell power density is given by

$$P = JV \quad (1)$$

P reaches a maximum at the cell's *operating point* or *maximum power point*. This occurs at some voltage Vm with a corresponding current density Jm. The *fill factor* is defined as the ratio

$$FF = (JmVm)/(JscVoc) \quad (2)$$

and describes the square ness of the J-V curve

The *efficiency* 'η' of the cell is the power density delivered at operating point as a fraction of the incident light power density, Ps,

$$\eta = JmVm/Ps \quad (3)$$

Efficiency is related to Jsc and Voc using FF,

$$\eta = JscVocFF/Ps \quad (4)$$

These four quantities Jsc, Voc, FF and η are the key performance characteristics of a solar cell. All of these should be defined for particular illuminating conditions. The standard test condition for solar cells is the Air mass 1.5 spectrum, an incident power density of 1000 Wm^{-2}, and a temperature of 25° C.

Methodology

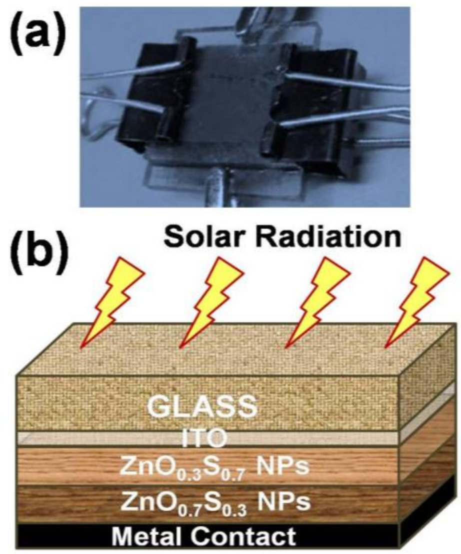

Figure 2: (a) The Actual experimental solar panel and (b) the schematics diagram of Solar Cell using ZnOS nanoparticles.

The Actual experimental solar panel and the schematics of this demonstrator Solar Cell using ZnOS nanoparticles is shown in figure 2. To demonstrator solar cell indium tin oxide (ITO, 1μm) coated glass plate was taken. On the ITO coated surface thin film (500nm) of NAC prepared $ZnO_{0.3}S_{0.7}$ nanoparticle was prepared by spin coating technique (in the 2cm × 2cm area) by successive coatings and allowed to dry at 60 C under vacuum. On this dried surface another thin film (500nm) of NAC prepared $ZnO_{0.7}S_{0.3}$ nanoparticles were made and again allowed to dry at 60 C under vacuum. Metal contacts were made on the top of the film surface. The biasing was performed between the ITO surface and the metal contact made at the top of deposited ZnOS film.

Process of Evaluation:

To determine the performance improvement of the nanophosphors layers of ZnOS, we deposited the layers of $ZnO_{1-x}S_x$ on the ITO coated glass substrates and measured the short circuit current density and as a function of open circuit voltage for Equation 4. Using such a structure comprising of two layers of $ZnO_{1-x}S_x$ with x=0.7 and x=0.3 respectively, as in Figure 1. We have covered the band gap from 300 nm - 500 nm, a region where Si-based solar cells are very inefficient. Our preliminary results, with no optimization give us 3 % enhancement in efficiency under solar spectrum. The spectral range (below 500 nm) is outside the Si-solar cell. Hence our concept of utilizing unused near UV/Blue radiation of solar spectrum can be down

converted to useful visible part of radiation by transparent coating of ZnOS nanophosphors. Figure 3 show the obtained JV Characteristics for the prepared solar cells and the calculated output parameters/performance characteristics for ZnOS Solar Cell are depicted in Table 1.

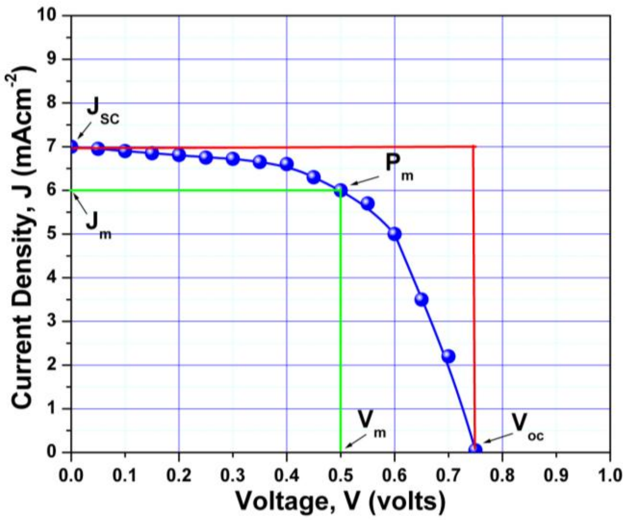

Figure 3: The JV Characteristics for the prepared solar cells.

TABLE 1:

Performance parameters characterizing ZnOS Solar Cells for a Ps = 0.1 W/cm^2

Cell Area (cm^2)	V_{oc} (mV)	J_{sc} (mA/cm^2)	Fill Factor (FF)	Efficiency (%)
4	75.0	7.0	572.0	3.0

To enhance the efficiency, we need to improve:

1. The efficiency of down conversion of these $ZnO_{1-x}S_x$ $(0 \leq x \leq 1.0)$ layers, by improving the x values and luminescence activator center.
2. Improve the interface between nanophosphors of Si solar cells, as well as optimizing the thickness (in mm) to absorb and down convert efficiently.

R N Bhargava
Nanocrystals Technology Limited
235 Elm Road, Briarcliff Manor NY

Avinash C Pandey
Nanophosphor Application Center
University of Allahabad, India